Is there a relationship between lumbopelvic muscle size and spinal curves in elite Australian Football League players?

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Is there a relationship between lumbopelvic muscle size and spinal curves in elite Australian Football League players?

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Abstract

Background

Preventing lower limb injuries in the Australian Football League (AFL) is a primary focus of medical teams across the competition. A smaller cross-sectional area (CSA) of the multifidus muscle has been identified as increasing the injury risk of AFL athletes. Understanding why this is a risk factor has been largely theoretical. It has been shown that increased volume of the multifidus and lumbar erector spinae muscles is related to increased curvature in the lower lumbar spine. Identification of the relationships between the CSA of the multifidus, sagittal spinal angles, as well as CSAs of other trunk muscles could help us better understand why multifidus muscle CSA is an injury risk factor for AFL athletes.

Method

This study was a cross-sectional observational study of 48 players at one AFL club. The CSAs of trunk and pelvic muscles (multifidus, lumbar erector spinae (LES), quadratus lumborum (QL), psoas major (PM) and gluteus maximus (Gmax)) were measured from magnetic resonance imaging (MRI). Internal oblique (IO) thickness was measured from ultrasound images and sagittal cobb angles of the thoracic kyphosis and lumbar lordosis were measured from a standing lateral X-ray. Pearson’s correlation coefficients were used to identify relationships between the muscles measured and the sagittal spinal angles of the spine.

Results

There were no correlations found between the sagittal spinal angles and the CSA of the muscles measured. Moderate positive correlations were found between: IO thickness and

LES at L_3 (r=0.40); LES (L_2, L_3) and Gmax (L_2 r= 0.49, L_3 r= 0.43); and PM and Gmax (r=0.5). Weak positive correlations were found between CSAs of the Gmax and the multifidus at L_4 (r=0.35); IO thickness and multifidus at L_4 (r=0.32); IO thickness and LES at L_2 (r=0.29); L_3 r=0.40); LES (L_2) and multifidus at L_5 (r=0.33)

Discussion

Contrary to results of other studies, the CSA of the multifidus muscles was not related to the lumbar lordosis. However, previous studies have predominantly been conducted on non-athletic populations. The multifidus and LES contribute to trunk extension (and anterior tilt of the pelvis), while the IO and Gmax contribute to trunk flexion (and posterior pelvic rotation). The PM and Gmax muscles primarily generate flexion (PM) and extension (Gmax) of the hip. This exploratory study showed correlations between agonists involved in hip and trunk extension (Gmax and multifidus/LES) and trunk extension (multifidus and LES). Correlations between antagonists were observed for muscles associated with trunk flexion/ extension (IO and multifidus/LES) and hip joint flexion/extension (Gmax and PM).

Conclusion

The results of this observational exploratory study indicated that there were not any significant correlations between the size of the sagittal curves of the spine and the size of key stabilizing muscles of the lumbopelvic region in elite AFL players. The reasons why a smaller CSA of the multifidus muscle is a lower limb injury risk factor may be complex and multifactorial.

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List of outputs from work

Conference Presentation::
“*Correlations between trunk muscle cross sectional areas and sagittal spinal curves in Australian Football athletes”.* Clint Frazer, Felix T Leung, Andrew Rotstein, M.Dilani Mendis, Julie Hides Presented at Sports Medicine Australia conference, Gold Coast, Australia (November 2022).

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the report contains no material previously published or written by another person except where due reference is made in the thesis itself.

Clint Frazer

List of Abbreviations

ACL	Anterior Cruciate Ligament
AFL	Australian Football League
AFLW	Australian Football League Women
BMI	Body Mass Index
CSA	Cross sectional area
EO	External Oblique
EMG	Electromyography
ES	Erector Spinae
Gmax	Gluteus Maximus
GPS	Global Positioning System
ICC	Intraclass Correlation Coefficient
IO	Internal oblique
LES	Lumbar Erector Spinae
MRI	Magnetic Resonance Imaging
PM	Psoas Major
QL	Quadratus Lumborum

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1. Introduction

Injuries in sport are costly for both professional and recreational athletes. Lower limb injuries make up a large proportion of these injuries. Preventing lower limb injuries can benefit professional sporting teams by improved player availability for games and improved team performance (Hägglund et al., 2013). The first step in preventing injuries is identifying injury risk factors for injury. While there are many intrinsic and extrinsic risk factors for injury, identification of modifiable intrinsic injury risk factors that are amenable to intervention is important in the management of athletes. One of these risk factors is having a small multifidus which is a spinal muscle. Decreased size of the lumbar multifidus muscle size has been shown to be related to injury in several sports (Fortin et al., 2019; Gildea et al., 2013; Hides et al., 2008; Hides et al., 2020; J. Hides et al., 2014; Hides & Stanton, 2017) and has been found to be a significant risk factor for injury in Australian football (Hides et al 2014, Hides and Stanton 2017, Hides et al 2020). Increasing lumbar multifidus muscle size through motor control training exercise has been shown to increase player availability for games (Hides & Stanton, 2012). However, we are yet to fully understand the mechanism by which this muscle can minimise injury risk for athletes. The action of the lumbar multifidus muscle is to maintain the arch, or spinal curve, in the lower back which allows for a better position to absorb and distribute forces (Bogduk et al., 1992; Ward et al., 2009). A larger multifidus muscle size has been shown to be correlated with an increased lumbar lordosis across a number of population types such as younger patients subjected to bed rest and older patients with degenerative spinal kyphosis (Belavy et al., 2011; Xia et al., 2019; Yang et al., 2021). However, this relationship has not been established in athletes. The multifidus muscle is not the only muscle believed to influence on spinal posture. Other muscles, namely the psoas major (PM), Gluteus Maximus (Gmax), Internal Oblique (IO), Erector Spinae (ES) and Quadratus Lumborum (QL) all have direct or fascial attachment to the spine or pelvis and can influence spinal posture. The relationship between the size of these muscles, the lumbar multifidus muscles and spinal posture has yet to be established in an athletic population.

Increasing our understanding of why decreased multifidus muscle size is an injury risk factor in Australian Football League (AFL) athletes, may enable more targeted application of injury prevention exercise programs. For example, if a relationship between the size of the multifidus muscles and the lumbar lordosis and thoracic kyphosis can be established, the results of this study could inform development of exercises using postural cues to increase recruitment of this muscle. Depending on their effects on the lumbar lordosis and thoracic kyphosis, exercises for muscles that have similar effects to that of the multifidus muscle on spinal posture could be integrated into new exercise programs aimed at increasing the size of the multifidus muscle, with an ultimate aim of increasing player availability of AFL athletes.

Therefore, the first aim of this project was to identify the relationship between the size of the lumbar multifidus muscles and football players' posture (amount of thoracic kyphosis and lumbar lordosis). As the multifidus muscles do not act in isolation, the second aim of this project was to identify the relationship between the size of other lumbopelvic muscles and the amount of thoracic kyphosis and lumbar lordosis, measured in degrees. Understanding the relationship between individual muscles and spinal posture may help to improve our understanding of the relationship between decreased size of the lumbar multifidus muscles and increased risk of injury.

The objectives of this project were to:

1. Investigate the relationship between size of the multifidus muscle and size of the angle (in degrees) of AFL players' standing spinal posture (i.e., thoracic kyphosis and lumbar lordosis)
2. Investigate the relationship between the size of key trunk and pelvic muscles also involved in lumbopelvic stability (internal oblique (IO), quadratus lumborum (QL), lumbar erector spinae (LES), psoas major (PM), gluteus maximus (Gmax)) and size of the angle (in degrees) of AFL players' standing spinal posture (i.e., thoracic kyphosis and lumbar lordosis)

3. Investigate the relationship between the size of the lumbar multifidus muscle and the size of other key muscles that attach to the spine and pelvis (IO, QL, LES, PM and Gmax)

The hypotheses of this study are:

1. The CSA of the lumbar multifidus muscle will be positively correlated with the size of the lumbar lordosis and thoracic kyphosis spinal angles.

2. The CSA of the muscles that increase the lumbar lordosis (LES, PM, QL) will be positively correlated with the size of the lumbar lordosis and thoracic kyphosis spinal angles. In contrast, the CSA of the muscles that reduce the lumbar lordosis (IO and Gmax) will have a negative correlation with the size of the lumbar lordosis and thoracic kyphosis spinal angles.

3. The CSA of the lumbar multifidus will be positively correlated with the muscles that

can increase the lumbar lordosis (LES, PM, QL). In contrast, the CSA of the lumbar multifidus will have a negative correlation with the muscles that can reduce the lumbar lordosis (IO, Gmax).

2. Literature Review

2.1 The Problem

Australian football is a contact sport with very high running demands and high risk of injury. Lower limb injuries make up 70% of the overall injury profile of players from the AFL. From 2009 to 2019, the average AFL injury incidence in the AFL was 741 injuries per year. This equates to 41.8 injuries per year for each team. Of these, 29.5 injuries per year occurred in the lower limb region with a loss of 127 player games per team, per year (AFL Doctors Association, 2019a). The loss of player games creates both a performance and financial cost to football clubs. The performance cost of a high injury rate in AFL has been shown to result in poorer team performance and lower playing season results, while a low injury rate has been linked to improved team performance and higher playing season results (Hoffman et al., 2020). In the AFL for every nine player games missed, the team finished one position lower on the results ladder at the end of the season (Hoffman et al., 2020). The effect of injury rates on performance has also been observed in other sports such as soccer, where lower injury burden and higher match availability resulted in teams scoring more points per match and increased final league rankings (Hägglund et al., 2013). The loss of player games is also accompanied by a financial cost for sporting clubs. It was estimated in 2012 that a single hamstring injury for an AFL player cost football clubs approximately $40,000 (Hickey et al., 2014). This amount would be significantly higher today due to the increases in player salaries since 2012. This cost has led to a focus on the identification of injury risk factors and implementation of injury prevention programs in elite level football clubs. The identification of risk factors such as high training loads (assessed using through global positioning systems (GPS)), insufficient adductor strength, decreased hamstring strength and fascicle length are examples of injury risk factors that have been identified in athletes competing in the AFL (Murray et al., 2017; Pizzari et al., 2008; Timmins et al., 2016). Interventions to address these risk factors such as eccentric hamstring strengthening exercises have led to a significant reduction in hamstring injury rates (Petersen et al., 2011; van der Horst et al., 2015). Currently, smaller size of the lumbar multifidus muscle has been identified as an injury risk factor for AFL athletes. Interventions can be targeted at increasing the size of this muscle group and have been shown to improve player availability (Hides & Stanton, 2012; Hides & Stanton, 2017). However, the underlying mechanism for these findings has not yet been determined.

2.2 Lumbopelvic stability and injury

Poor lumbopelvic stability has long been identified as an injury risk factor in athletes, despite the difficulties associated with defining and quantifying its existence (Chaudhari et al., 2014; Hides & Stanton, 2014; J. A. Hides et al., 2014; Schuermans, Danneels, Tiggelen, et al., 2017). Lumbopelvic stability has been described as the ability to maintain optimal alignment of the spine, pelvis and thigh to optimise force transfer from the lower limbs to the trunk and upper limbs and from the upper limbs to the trunk and lower limbs (Kibler et al., 2006; Wilke et al., 1995). Research attempting to quantify lumbopelvic stability has involved both structural measures (e.g., pelvic and lower limb angles and muscle size) and functional measures (e.g, strength and activation of the trunk muscles) in both static postures and during functional tasks (De Bleecker et al., 2020; Emami et al., 2018; Hides et al., 2008; J. Hides et al., 2008; Janse van Rensburg et al., 2017; Schuermans, Danneels, Van Tiggelen, et al., 2017). Measuring the cross-sectional area (CSA) of muscles attaching to the spine and pelvis has allowed quantification of one of the structural component associated with lumbopelvic stability in athletes (Hides & Stanton, 2012; J. Hides et al., 2008; Sitilertpisan et al., 2011). While there is not a gold standard for measuring lumbopelvic stability, an increase in muscle CSA has been shown to be correlated with higher measures of muscle strength (Masuda et al., 2003). An increase in muscular strength allows for greater co-contraction when stabilising the lumbopelvic region, and increased stiffness of the spine allows muscle groups to move the distal limbs more effectively (Kibler et al., 2006). Measuring the size of individual muscles also aims to identify muscle imbalances that could increase an athlete's risk of injury. Identification of specific deficits in muscles also allows more accurate exercise prescription. While all trunk muscles are important in stabilising the lumbopelvic region, a smaller multifidus muscle has been identified as an injury risk factor in AFL athletes.

2.3 Multifidus muscle size is a modifiable injury risk factor

Of the trunk muscles that have been investigated, smaller size of the lumbar multifidus muscle has consistently been associated with higher risk of injury in AFL athletes (Hides et al., 2020; Hides & Stanton, 2014; Hides & Stanton, 2017; J. A. Hides et al., 2014). In a sample of 261 AFL players, it was reported that for every one cm^2 decrease below the mean in CSA of the multifidus muscle at the L_5 veterbral level, there was an increase in risk of lower limb injury (odds ratio (OR) = 2.43) (Hides & Stanton, 2014). In the same sample, this risk was shown to increase when the CSA of the QL was accounted for (OR = 5.29) (Hides & Stanton, 2017). More recently, when adjusting for CSA of the QL muscle, player age and body mass index (BMI), the risk of a lower limb injury was 2.38 times less likely for every one cm^2 increase above mean in CSA of the multifidus muscle CSA at the L_5 vertebral level (Hides et al., 2020).

The relationship between the multifidus muscles and injury has also been investigated in other sports such as soccer and rugby union. In soccer players, atrophy of the multifidus muscles over the playing season (measured by muscle thickness) was associated with experiencing a lower limb injury during the season (Nandlall et al., 2020). A study of the lumbar multifidus muscles in university rugby union players showed that players who had a lower limb injury in the previous 12 months had greater between side asymmetry of the CSA of the multifidus muscles (Levesque et al., 2020). Another study of rugby union players identified that decreased ability to contract the lumbar multifidus was associated with lower limb injuries during the rugby union pre-season (Roy et al., 2021). While the rationale underpinning these findings may be debatable, the findings are relevant when trying to prevent injuries in athletes.

In contrast, further research into AFL and rugby league players have tried to replicate the findings of Hides and Stanton (J. Hides et al., 2014). In 238 athletes across two sports (AFL n = 87; Rugby league n = 151), the clinical cut-off for multifidus muscle CSA (Hides et al., 2020) was used to dichotomised players into "at risk" (< 8.5cm^2) and "not at risk" (> 8.5 cm^2) groups. The clinical cut-off derived from the AFL players did not predict non-contact lower limb injuries in these players (Hajek et al., 2021). However, in support of the previous results of Hides and Stanton (2014), having a QL muscle CSA > 8.2cm^2 significantly increased the risk of injury in AFL athletes (OR = 3.08; CI 1.09 – 8.64) (Hajek et al., 2021). The L_5 multifidus to QL ratio was not found to be a significant risk factor in either AFL or rugby league players (Hajek et al., 2021). However, the number of injuries amongst the AFL players was significantly lower than those reported by Hides and Stanton (2014) which may be one factor contributing to the difference in findings. Furthermore, the clinical cut-off derived from players in the AFL may not have been suitable for use in rugby league players, as the sports have very different demands and the morphology of the players is quite different across sports. Comparing results across different sports is difficult as the physical demands across sports will change the injury profile. Both, Roy et al. (2021) and Levesque et al (2020) included male and female players in their studies. It is important to note the injury profile between male and female athletes can be significantly different. Across the 2018 and 2019 AFL and AFLW seasons, the total injury incidence per 1000 hours was 37.8 and 26.4 respectively. Hip, groin and thigh injuries made up 34.2% of these injuries in the AFL while it only represented 13.5% of injuries in the AFLW. For anterior cruciate ligament (ACL) injuries, the incidence per 1000 hours was found to be 5-6 times higher in the AFLW than in the AFL (AFL Doctors Association, 2019a, 2019b). These differences may therefore affect the injury profile and the subsequent risk factors for each sport. Currently, the majority of findings support the relationship between multifidus muscle size as an injury risk factor, particularly in AFL athletes.

Multifidus muscle size has been shown to change across a football playing season. In a longitudinal study of 20 AFL players, there was a statistically significant ($p < 0.05$) reduction of the CSA of the multifidus muscle ranging from 3.8% to 11.1% across the L_3 to L_5 vertebral levels, over the course of the season (Hides & Stanton, 2012). A decrease in multifidus muscle thickness has also been observed across the course of a playing season in soccer players (Nandlall et al., 2020). This may be due to multiple factors such as lower training volumes, particularly strength training in the playing season. However, with the size of the multifidus muscle reducing throughout the year associated with playing games, there could be a place for exercise interventions aimed at minimising this reduction across the playing season. The implementation of a motor control exercise intervention across the AFL season has shown an increase in multifidus size by 10.4% on average across the L_2 – L_5 vertebral levels in an intervention group (Hides et al., 2012). With a stepped-wedged intervention design, players that participated in a structured exercise program earlier in the season had increased match availability than those who received the intervention later in the year (Hides et al., 2012). A further study of 242 AFL players was able to minimise the reduction of the multifidus muscle CSA across the season in players that participated in a self-guided exercise program (Hides et al., 2017). The increase in the size of the multifidus muscle with exercise interventions is thought to improve lumbopelvic stability and consequently reduce the risk of injury in AFL players.

2.4 The role of the multifidus muscle in lumbopelvic stability

The multifidus muscle is one lumbopelvic muscle that contributes to the stability and protection of the lumbopelvic region. Its action is to maintain the lumbar lordosis in both static and active postures and optimise force transfer from the lower limbs to the upper limbs and vice versa (Bogduk et al., 1992; Wilke et al., 1995). Due to the LES muscle terminating at the L_4 vertebrae, the multifidus muscle is the largest trunk extensor muscle at the lumbosacral junction (Rosatelli et al., 2008). The large proportion of type I muscle fibres and a large capillary network which provides high levels of oxygenation to the muscle fibres denotes a primary stabilising role (Agten et al., 2020). The multifidus also has a high concentration of muscle spindles allowing it to provide proprioceptive feedback regarding the position of the lumbopelvic region (Nitz & Peck, 1986). At the fibre-bundle level, the multifidus has significantly greater stiffness than other erector spinae muscles indicating a greater contribution to passive stability of the spine (Ward et al., 2009). While the multifidus contributes to extension, ipsilateral rotation and lateral flexion of the lumbar spine, its short length and small moment arm limits its contribution to spinal movement. Rather, the morphology of the multifidus muscle would indicate that it has a greater role in maintaining the lumbar lordosis and increasing the ability of the spine to tolerate compression loads (Patwardhan et al., 1999). Therefore, a larger multifidus muscle would indicate a greater ability to maintain the lumbar lordosis and improved lumbopelvic stability.

2.5 Lumbar Lordosis and lumbopelvic stability

The lumbar lordosis is an important structural feature required to maintain an upright posture (Sparrey et al., 2014). Maintaining the lumbar lordosis has been shown to increase the capacity to tolerate compressive loading of the lumbar spine (Patwardhan et al., 1999). A flexed posture of the lumbar spine reduces the moment arm of the extensor muscles and transfers load from active tissue (muscles) to passive tissues (intervertebral disc and ligamentous structures) (McGill et al., 2000). Maintaining a lumbar lordosis increases the activation of the extensor muscle group (multifidus and erector spinae) the deep abdominal muscles (Internal oblique and transversus abdominis) and the superficial abdominal muscles (external oblique and rectus abdominus) creating a “corset support” for the lumbopelvic region (Bogduk et al., 1992). The increase in activation of these muscles has been shown to increase the tolerance to shear forces across the lumbopelvic region (Goel et al., 1993). Tolerating high loads across the lumbopelvic region is important in contact sports and the correlation between CSA of the lumbopelvic muscles and the lumbar lordosis would support the use of injury prevention exercises aimed at maintaining the lumbar lordosis and increasing multifidus activation with movement. While there are many structures that contribute to the support of the lumbar lordosis, the support from key muscles is seen as the most modifiable.

Identifying the relationships between these key muscles with posture of the spine may identify exercise interventions that could be used to improve lumbopelvic stability.

2.6 Spinal posture and muscle size

The muscles attaching to the spine provide a significant contribution to lumbopelvic stability via their influence on spinal posture. The relationship between spinal posture and CSA of the multifidus muscle CSA has to date only been investigated in non-athletic populations. The size of the lumbar multifidus muscle, measured both in isolation and measured together with the LES muscle has been shown to have weak to moderate positive correlations with radiological measurements of the lumbar spine lordosis (Meakin et al., 2013; Menezes-Reis et al., 2018). These findings are similar in older patients diagnosed with degenerative spinal kyphosis (Xia et al., 2021). When deconditioning is analysed in extreme conditions, this relationship is even stronger. In astronauts experiencing 6 months of microgravity, a positive, strong correlation between a reduction in the CSA of the multifidus muscle and a reduction in lumbar lordosis ($r = 0.86$; $p < 0.05$) has been observed (Bailey et al., 2018). Similar results were found in bed rest studies where deconditioning resulted in a smaller CSA of multifidus and a flattening of the lumbar lordosis (Belavy et al., 2011). In younger active populations, this correlation is less obvious. In US marines, extensor muscle volume did not correlate with their lumbar Cobb angle, sacral slope or angle with respect to their horizontal measurements (Berry et al., 2018). However, fractional anisotropy, a measure of muscle fibre density, was significantly correlated with measurements of the lumbar lordosis, suggesting that muscle microstructure including fibre density, as opposed to muscle size may be more significant in this population demographic (Berry et al., 2018). These findings suggest that a positive relationship has been shown to exist between the lumbar lordosis and the size of the spinal extensor muscles, particularly in older populations, those exposed to deconditioning environments and those with degenerative spinal disease.

The implications of these findings are that a loss of the lumbar lordosis has been shown to be associated with changes in the microstructure and the size of the multifidus muscle. Identifying correlations between a modifiable factor (lumbar extensor muscle CSA) and the spinal posture of athletes, would provide a rationale for targeted interventions aimed at improving the size of the multifidus muscle and the capacity of the spine to tolerate load.

2.7 Lumbopelvic muscular support in the sagittal plane

It is not only the muscles of the spine that contribute to spinal stability. Spinal stability relies on both the passive (bone, ligamentous and intervertebral disc) and active (muscle contraction) restraints to transfer compressive loads across the lumbopelvic junction. In biomechanical models, the addition of muscular forces results in a reduction of anterior-posterior translation of the vertebral segments, reduced intradiscal pressure and reduced shear forces across the intervertebral segments, indicating muscles attaching to the spine have a stabilising role across the lumbar vertebrae (Goel et al., 1993; Kong et al., 1996). Some other key muscles besides the multifidus believed to contribute to lumbopelvic stability and sagittal spinal posture include the PM, Gmax, IO, LES and QL. The current investigation aimed to investigate the relationship between these muscles supporting the sagittal spinal curves and the radiological angles of the lumbar lordosis and thoracic kyphosis. Theoretically, the PM, LES and QL muscles are anatomically placed for their contraction to increase the lumbar lordosis. The PM muscle attaches to the anterior vertebral bodies of the lumbar spine and its contraction is thought to support the lumbar lordosis (Santaguida & McGill, 1995). At the muscle fibre level, the architecture of the PM muscle supports its role as both a dynamic hip flexor and stabiliser of the spine (Regev et al., 2011). The fibre type of the PM muscle has been shown to consist of predominately type I fibres at its proximal end, which denotes a possible role in spinal stability role (Arbanas et al., 2009). Given the high kicking demands of AFL athletes, understanding the size of the PM muscle in relation to the sagittal spinal angles would increase our understanding of the stabilising role of the PM muscle in athletes. The LES muscle group attaches to the iliac crest, sacrum and erector spinae aponeurosis and extends to attach onto the transverse processes of the lumbar vertebrae, ribs and transverse processes of the thoracic spine. These attachments allow the LES muscle to exert an extension force on the spine and increase the lordotic spinal curve (Claus et al., 2009). The QL is positioned to exert lateral flexion, extension and compression forces on the lumbar spine. However, the magnitude of these forces when modelled were no greater than 10% of that of the multifidus and LES (Phillips et al., 2008). While only a small contributor to extension of the lumbar spine, the CSA of the QL has been identified as a risk factor for injury in AFL athletes (Hides et al., 2020). As the PM, LES and QL muscles together with the multifidus muscles contribute to maintaining the lumbar lordosis, understanding the relationship between these muscles and the sagittal spinal curves could assist in identifying AFL athletes at risk of injury.

The IO and Gmax muscles are anatomically placed for them to reduce the lumbar lordosis by inducing a posterior pelvic tilt of the pelvis. The IO muscle originates from the lower ribs and attaches to the inguinal ligament and Iliac crest (Urquhart et al., 2005). Its primary action is to posteriorly rotate the pelvis, compress the abdominal contents and together with other trunk muscles, increase the stiffness of the lumbar spine. This increase in stiffness influences lower limb biomechanics. In landing tasks, an increase in ground reaction force and reduction in hip and knee angles upon landing has been associated with increasing abdominal bracing (Campbell et al., 2016). This reduction in absorption of force has been identified as a risk factor for lower limb injuries (Taborri et al., 2021). While measuring the CSA of the IO is not possible due to the thin shape of the muscle, the thickness of the muscle can be used as a measure of the morphology of the muscle. Among other morphological variables, muscle thickness measured via ultrasound imaging has a strong correlation with muscle strength (Stock et al., 2017). A thinner IO would indicate reduced strength to stiffen the spine and posteriorly rotate the pelvis. The Gmax is another muscle that can contribute to posterior rotation of the pelvis and reduce the lumbar lordosis. While the main role of the Gmax muscle is to extend the hip, its proximal attachment to the iliac crest and thoracolumbar fascia would allow it to exert an extension force on the lower lumbar segments as well as impart a posterior rotation force on the pelvis (Barker et al., 2014). The relationship between gluteal muscle strength and activation with risk of lower limb injury risk is complicated. A reduction in hip strength has been identified as a risk factor for lower limb injuries, particularly ACL injuries (Khayambashi et al., 2016). Furthermore, a reduction in activation of the Gmax muscle during the terminal swing phase of sprinting has been shown to be associated with a higher risk of hamstring injuries in soccer players (Schuermans, Danneels, Van Tiggelen, et al., 2017). Conversely, higher activation of the gluteus medius muscle has been shown to be associated with a higher risk of hamstring injury in AFL players (Franettovich Smith et al., 2017). These studies indicate that gluteal muscles have a role to play in lower limb injury prevention, but the relationships are complex in that sometimes injuries are associated with increased recruitment of muscles, or they can be associated with decreased recruitment of muscles. Identifying the relationship between muscles that posteriorly tilt the pelvis and sagittal spinal curves will enhance our understanding of mechanisms that could possibly prevent soft tissue injuries in athletes.

2.8 The Need for Further Research

Identifying modifiable injury risk factors is of high importance for medical staff supporting the health of an elite level football player. Minimising the risk of injury has both financial and team performance benefits for AFL clubs, as well as improving the safety for players participating. The multifidus muscle has been shown to contribute to stability of the lumbopelvic region, and a smaller CSA of the muscle has been identified as an injury risk factor for AFL athletes. How a smaller multifidus muscle results in an increased risk of injury is largely theoretically based. Identifying the relationships between the lumbar multifidus muscle, other muscles controlling sagittal spinal stability and sagittal spinal angles could improve our understanding as to why reduced multifidus size is an injury risk factor in AFL athletes. Therefore, this study aims to investigate the interrelationship between the CSA of key lumbopelvic muscles and the radiological measurements of the sagittal curves of the spine in AFL athletes.

3. Methods

3.1 Study Design

A cross-sectional observational study was conducted to investigate the relationship between the size of lumbopelvic muscles and spinal posture in Australian Football League players. All participants were assessed over two days during the preseason period (January). The research protocol involved data collection in the form of (i) questionnaires, (ii) muscle size imaging and measurements using ultrasound imaging, (iii) magnetic resonance imaging (MRI) and (iv) Standing X-ray imaging of the spine.

The study was approved by the relevant Human Research Ethics committee of the host institution (Q201174) and the industry partner. Players involved were provided with a written description of the study procedure and provided written, informed consent.

3.2 Participants

Players from one professional club in the Australian Football League were recruited for participation in this study. All 48 male players representing the full training squad were available for the study. Players were provided with a participant information sheet describing the study procedure. Written consent was obtained from participants. All players had the option to decline participation or withdraw from the study at any time without penalty. Players were excluded from the study if they had metal implants, claustrophobia or any other contraindication to MRI. Players were also excluded if they presented with previous spinal surgery, structural spinal deformity or substantial low back pain lasting longer than 3 months. No players were excluded from the study.

3.3 Questionnaires

Self-administered questionnaires were used to collect data on player demographics (age, training age, height, weight). Information regarding history of injuries and spinal pain were collected. No players had previous spinal surgery, structural spinal deformity or substantial low back pain lasting longer than 3 months. All available players were included in the study. There were no female athletes included due to season scheduling and availability.

3.4 MRI Assessment

3.4.1 Imaging Protocol

All players underwent a medical screening and metals safety check prior to undergoing MRI on a Siemens 3 Tesla Magnetom Verio MR system (Siemens, Erlangen, Germany). Players were placed in a supine position as seen in figure 1, and transverse images were taken at rest. Three T2 weighted axial sequences were taken. Two T2 weighted sequences of the lumbar spine paravertebral musculature (repetition time = 4660 ms, echo time = 87 ms, flip angle = 120°, field of view 260mm, and number of averages = 1) were employed to maximize clarity and definition of the fascial borders. The first T2 sequence was from the T_{12} to S_2 vertebral level in the axial plane parallel to the patient's body to best assess the PM and QL muscles. The second T2 sequence was taken from the L_3 to S_2 vertebral level parallel to the $L_4/_5$ disc to best assess the multifidus muscles. The third T2 sequence was taken from the top of the iliac crest to the inferior gluteal fold. The entire pelvis was included in this field of view, to allow simultaneous capture of the Gmax muscle on both sides (repetition time = 7610 ms, echo time = 87 ms, flip angle = 120°, field of view 380mm, and number of averages = 1). All images were performed by an expert radiologist at Victoria House Medical Imaging, Prahan, Victoria, Australia. Total scanning time per player was 15 minutes.

3.4.2 Measurement of muscle size

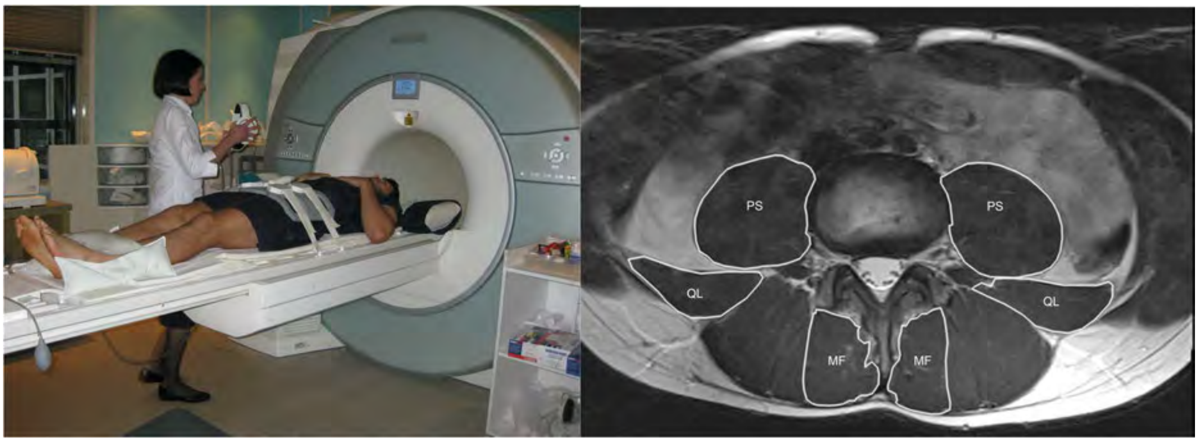
MRI images were de identified and saved for measurements to be conducted at a later date using an image analysis software program (OsiriX, Pixmeo SARL, Switzerland). The CSAs of the multifidus, QL, Gmax, and LES muscles were measured by manually tracing the borders of the muscles (Figure 1). The multifidus muscle was measured at two vertebral levels (L_4 and L_5), as these vertebral levels are those where the multifidus muscle is the largest. The CSA of the QL muscle was measured at the level of the L_{3-4} intervertebral disc, where it is also largest (Stewart et al., 2010). The CSA of the Gmax muscle was measured at the level of the femoral head. The CSA of the PM muscle was measured at the L_{4-5} vertebral disc (Stewart 2010 et al). The LES was measured at the lower end plate of L_2 and L_3 vertebrae as this is the largest portion of the LES. The measurements were conducted by a member of the team (JH) with established reliability in the measurement technique. Reliability statistics for measuring these lumbopelvic muscles have been previously reported with intraclass correlation coefficients ranging between 0.95-0.98 (Hides et al., 2010; Hides, Belavý, et al., 2007; Hides, Miokovic, et al., 2007; Stewart et al., 2010).

3.4.3 Measurement of lumbar lordosis

The lumbar lordosis was measured on MRIs using the lumbar lordotic Cobb angle. A line was drawn from the superior endplate of the L_1 vertebra and the Inferior endplate of the L_5 vertebrae. The Cobb angle was measured at the intersection of these lines by a trained radiologist.

Figure 1:

a) MRI participant position b) MRI Measurement of muscle cross sectional area.



PS psoas; QL Quadratus Lumborum; MF multifidus

3.5 Ultrasound Assessment

3.5.1 Imaging protocol

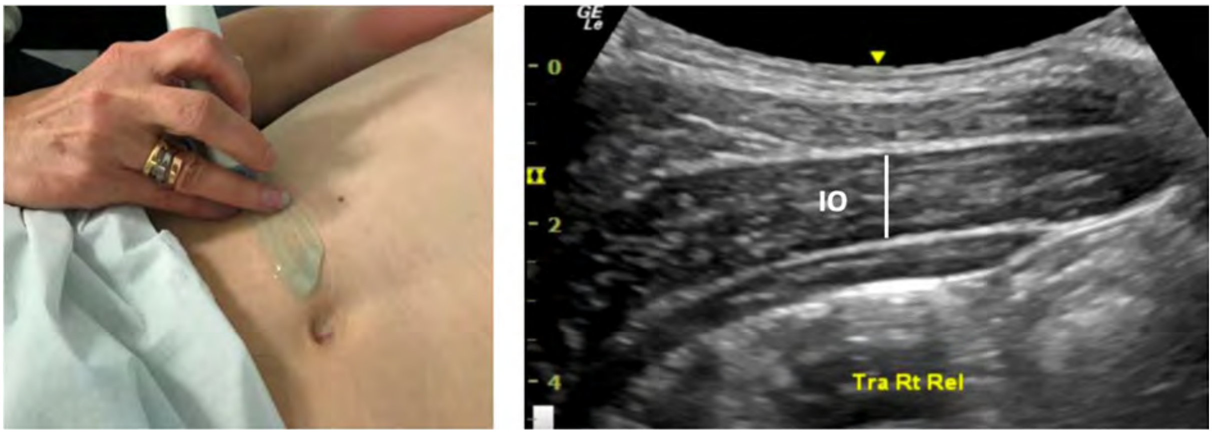
Ultrasound imaging was used to measure the thickness of the IO muscles at rest. The magnetic resonance imaging sequence used provided high resolution images of the paraspinal muscles, but not the abdominal muscles (in the one transverse image). The IO muscle was chosen for inclusion in this study rather than the transversus abdominis muscle, as it is a torque producing muscle that has the capacity to posteriorly tilt the pelvis or flex the thoracolumbar spine and therefore influence spinal posture. Although the external oblique (EO) muscle is also a torque producer capable of posteriorly tilting the pelvis, it was not measured in this study. Due to the oblique orientation of its fibres. Measurements of muscle thickness of the EO muscle in the transverse plane are thought to be less representative of muscle contraction than the IO muscle (Hodges et al., 2003), hence the decision to measure thickness of the IO muscle. The transducer was placed midway between the inferior rib cage and the Iliac crest for the left and right sides (Figure 2). To standardise the position of the transducer, all images included the anterior fascial insertion of the transversus abdominis within the field of view when the subject was relaxed. The images were conducted by a member of the research team (JH) with established reliability (ICC 0.99) (Hides, Miokovic, et al., 2007).

3.5.2 Measurement of muscle thickness

Images were stored on a hard drive and measured off-site using OsiriX image analysis software program by members of the team with demonstrated reliability in conducting the measurements (ICC = 0.99; (Hides, Miokovic, et al., 2007)). The thickness of the IO muscle was defined as the distance between the superior and inferior muscle fasciae of each muscle.

Figure 2:

A) Ultrasound imaging of the IO muscle with the transducer placed transversely midway between the inferior rib cage and the iliac crest. B) The thickness of the internal oblique (IO) muscle.



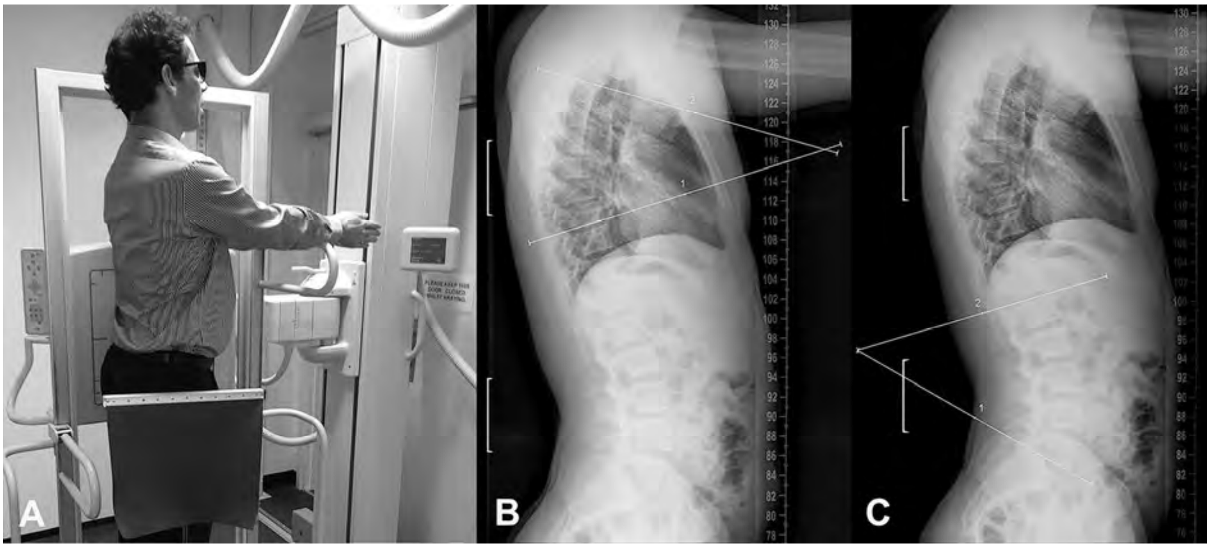
IO Internal oblique

3.6 X-Ray Assessment

A lateral erect x-ray of the spine was performed by a qualified radiologist in a private radiology clinic to allow calculation of the angles of the thoracic kyphosis and lumbar lordosis. The standing position of the x-ray was standardised with the arms resting on a rail out in front of the body to avoid obstruction of the x-ray. The thoracic kyphosis was measured using a Cobb angle from the superior endplate of T_4 and the inferior endplate of the T_9 vertebrae (Briggs *et al.* 2007) (Figure 3B). The lumbar lordosis was measured using the lumbar lordotic Cobb angle from the superior endplate of L_1 and the Inferior endplate of the L_5 vertebrae (Figure 3B). Measurements were performed on a digital imaging PACS system and were conducted by a trained radiologist.

Figure 3:

A) Position of X-ray assessment B) Measurement of thoracic kyphosis cobb angle C) measurement of lumbar lordosis cobb angle



3.7 Statistical Analysis

Variables were checked for normal distribution using summary statistics, histograms, normality plots and the Kolmogorov-Smirnov tests. Comparisons of between side differences (left vs right) for the size of all muscles (L_4 and L_5 multifidus, LES, Gmax, PM, IO and QL) were conducted using independent samples t-test. No significant differences were found between the left and right sides across all muscle groups therefore, muscle size was averaged across sides for use in the main analysis. Relationships between demographic variables and averaged muscle size measurements were assessed using Pearson's correlation coefficient (r). To answer the aims of the study, relationships between muscle size and spinal angles were assessed using Pearson's Correlation Coefficient. The r values were interpreted as weak (≤ 0.39), moderate (≥ 0.40–0.69), or strong (≥ 0.70). As this was an exploratory study, and in order to minimise type II errors, no adjustments for multiple comparisons were made (Bender & Lange, 2001). The significance level was set at $p \leq 0.05$. All statistical analyses were performed using IBM SPSS Statistics software (version 26; SPSS, IBM Corp., Armonk, NY, USA). All cases were analysed.

4. Results

4.1 Player demographic

Player demographics were calculated as mean (SD). The mean player age was 22.8 years old (+/- 3.1 years), training age was 5.4 years (+/- 3.5 years), height was 188 centimetres (+/- 6.7 cm) and weight was 87 kilograms (+/- 8.4 kg). Left to right comparisons were conducted for all muscle CSAs and thickness of the IO muscle using independent T-tests (Supplementary table 1). The relationship between player demographics and muscle size is shown in Table 1.

Table 1: Relationship between player demographics and muscle size

		Age (years)	Training age (years)	Height (cm)	Weight (kg)
L5 multifidus CSA (cm^2)	**r**	**-0.31***	-0.26	0.19	**0.32***
L4 multifidus CSA (cm^2)	**r**	-0.24	-0.25	0.24	**0.35***
QL CSA (cm^2)	**r**	-0.16	-0.24	0.06	0.21
PM CSA (cm^2)	**r**	0.03	0.07	0.20	0.32*
Gmax CSA (cm^2)	**r**	0.16	0.16	**0.54****	**0.70****
IO thickness (cm)	**r**	-0.07	-0.14	0.22	**0.38***
L2 ES CSA (cm^2)	**r**	0.11	0.12	0.26	**0.58****
L3 ES CSA (cm^2)	**r**	0.24	0.03	**0.31****	**0.56****

Gmax: gluteus maximus; QL quadratus lumborum; IO internal oblique; ES erector spinae; PM psoas major; CSA cross section area; cm centimetres; Kg kilograms. $p < 0.05$*; $p < 0.001$**

4.2 Lumbopelvic muscle size and spinal angles

The correlation between spinal angles and muscle CSA is presented in Table 2. There were no significant correlations between the CSA of the multifidus muscle and thoracic or lumbar spinal Cobb angles ($r < 0.39$; $p>0.05$). There were no significant correlations observed between the CSAs of other lumbopelvic muscles or the thickness of the IO muscle and thoracic or lumbar spinal angles (all $r < 0.39$; all $p > 0.05$). There was a strong correlation between the Cobb angle measurements from standing X-rays and those obtained using measures from MRIs with the participants positioned in supine lying ($r = 0.80$; $p < 0.001$).

Table 2: Correlation of average muscle size to thoracic and lumbar spinal angles

		X-Ray Lumbar Spinal Angle	**X-Ray Thoracic Spinal Angle**	**MRI Lumbar Spinal Angle**
Gmax CSA (cm^2)	**r**	-0.02	-0.09	-0.11
QL CSA (cm^2)	**r**	0.04	0.09	0.15
PM CSA (cm^2)	**r**	-0.25	-0.14	-0.17
IO Thickness (cm)	**r**	-0.17	0.03	-0.19
L2 ES (cm^2)	**r**	0.12	0.01	0.03
L3 ES (cm^2)	**r**	0.09	0.27	0.01
L4 Multifidus CSA (cm^2)	**r**	0.03	-0.16	-0.06
L5 Multifidus CSA (cm^2)	**r**	0.13	0.08	-0.11

Gmax: gluteus maximus; QL quadratus lumborum; IO internal oblique; ES erector spinae; PM psoas major; CSA cross section area; cm centimetres

4.3 Relationship between multifidus muscle size and other lumbopelvic muscles

The correlation between the muscle size variables is presented in (Table 3).

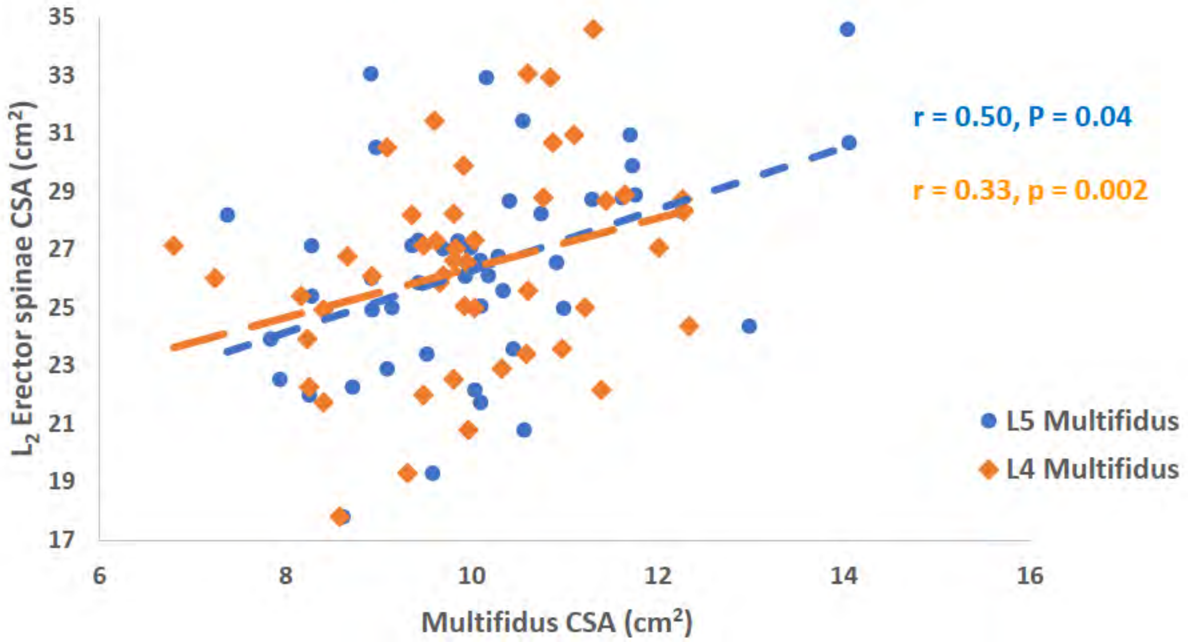
Table 3: Correlation of multifidus size and other spinal muscle size

		L4 Multifidus CSA (cm^2)	L5 Multifidus CSA (cm^2)	Gmax CSA (cm^2)	QL CSA (cm^2)	PM CSA (cm^2)	IO Thickness (cm)	L_2 ES CSA (cm^2)	L_3 ES CSA (cm^2)
L4 Multifidus CSA (cm2)	r	1							
L5 Multifidus CSA (cm2)	r	0.63**	1						
Gmax CSA (cm^2)	r	0.35*	0.21	1					
QL CSA (cm^2)	r	0.12	0.19	0.13	1				
PM CSA (cm^2)	r	0.01	-0.08	0.50**	0.18	1			
IO Thickness (cm)	r	0.32*	0.28	0.23	0.18	-0.16	1		
L_2 ES CSA (cm^2)	r	0.50*	0.33*	0.49*	0.08	0.17	0.29*	1	
L_3 ES CSA (cm^2)	r	0.17	0.21*	0.43*	0.09	0.15	0.40*	0.74**	1

Gmax gluteus maximus; QL quadratus lumborum; IO internal oblique; ES erector spinae; PM psoas major; CSA cross section area; cm centimetres; * $p < 0.05$; ** $p < 0.001$

Figure 4:

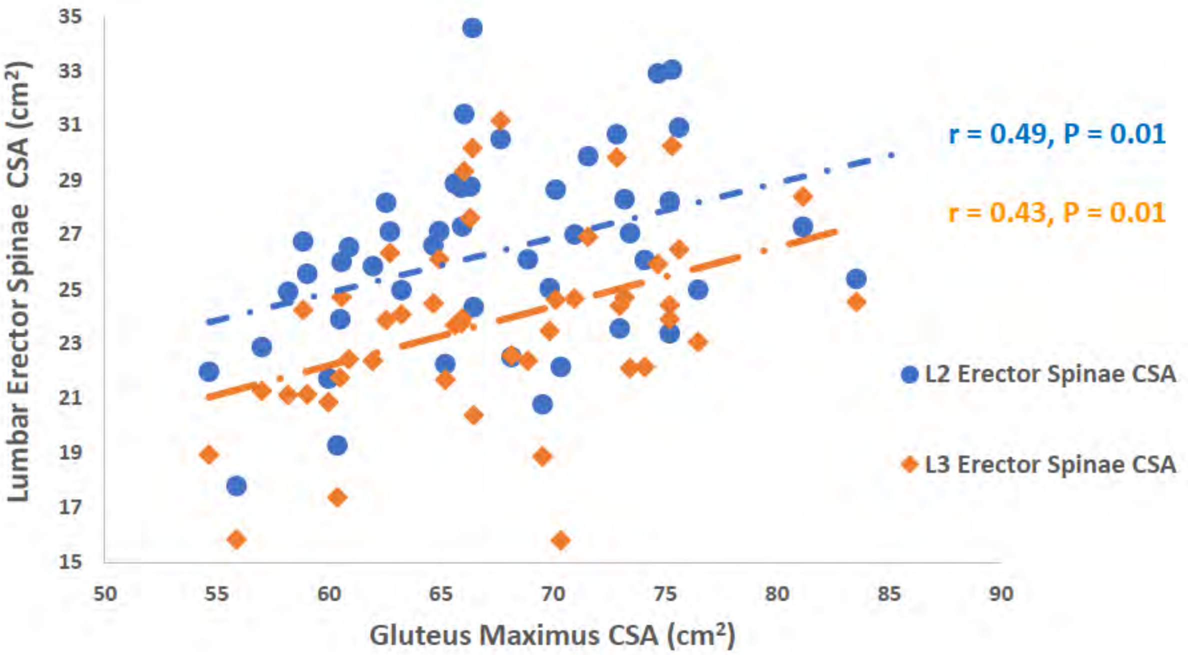
L_2 Erector Spinae muscle CSA correlation with L_4 and L_5 Multifidus muscle CSA



Gmax gluteus maximus; cm centimetres; CSA cross sectional area

Figure 5:

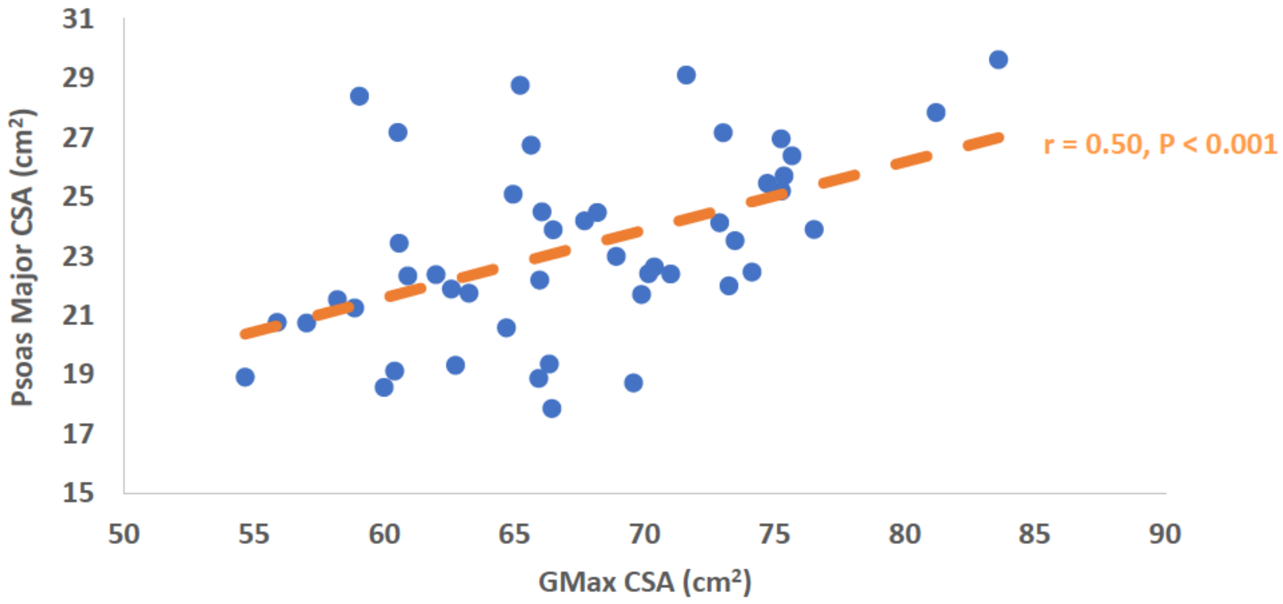
L_2 and L_3 Erector Spinae muscle CSA correlation with Gluteus Maximus muscle CSA



Gmax gluteus maximus; cm centimetres; CSA cross sectional area

Figure 6:

Psoas Major muscle CSA correlation with Gluteus Maximus CSA



Gmax gluteus maximus; cm centimetres; CSA cross sectional area

5. Discussion

5.1 The relationship between multifidus muscle and spinal posture

The first objective of the study was to identify the relationship between the CSA of the multifidus muscle at the L_4 and L_5 vertebral levels and the sagittal curves of the spine in elite AFL athletes. Our results indicated that the CSA of the multifidus muscle and the size of the lumbar lordosis or thoracic kyphosis were not correlated in AFL athletes. This finding is similar to those found in United States military recruits where a correlation was not found between the multifidus muscle volume and the lumbar lordosis measurements in three functional positions using MRI (Berry et al., 2018). The high training loads of athletes may be one reason why the correlation between multifidus muscle size and size of the sagittal spinal curves was not evident, as has been seen in other populations. The relationship was found to exist in older, less active population groups. showed. In a middle aged, healthy female population there was a positive correlation (r = 0.61; p < 0.001) between lumbar extensor muscle volume and lumbar spine lordosis (Meakin et al., 2013). Also, degenerative changes such as an increase in thoracic kyphosis associated with ageing was found to be related to reduced CSAs of the lumbar multifidus and ES muscles (Xia et al., 2019) and decreasing pelvic inclination was related to decreasing multifidus size in an ageing population (Masaki et al., 2015). Similar findings have been found in younger populations when exposed to the extreme inactivity of bed rest. After 60 days of bed rest, there was significant atrophy of the lower lumbar multifidus and ES muscle groups as well as a reduction in the lumbar lordosis (Belavy et al., 2011). This may suggest that a reduction in activity both acutely with bed rest and over time as a part of ageing, influences both the size of the lumbar extensor muscle group and the size of the lumbar lordosis. In the current study, a reduced multifidus muscle was not correlated with the size of the sagittal spinal curves. The characteristics of the population studied (e.g., age and activity level) may be one explanation for the lack of findings.

5.2. The relationship between lumbopelvic muscles and spinal posture

The second objective of this study was to explore the relationships between key stabilising muscles of the spine and the sagittal curves of the spine. Our results demonstrated that the sagittal spinal curves and the CSAs of all the muscles measured were not correlated. These results again are similar to those found in US military recruits, where a relationship was not found between measures of the lumbar lordosis and the volumes of the LES, QL or PM muscles (Berry et al., 2018). The lack of correlation between spinal posture and spinal stabilising muscle size seen in athletic populations may indicate there is a protective effect of high training loads that maintains muscle size despite the spinal postures adopted in athletic populations.

The curvatures of the lumbar and thoracic spine are likely to have numerous modifiable and non-modifiable factors that influence the degree of sagittal curvature. These could include passive tissue qualities such as stiffness of the ligaments and intervertebral discs, structural differences in pelvic inclination angle or habitual postures developed over a long period of time. It is beyond the scope of this study to determine the cause of the degree of spinal curvature. However, the lack of correlations between the sagittal spinal curves and the size of the muscles measured indicates that these muscles had little influence on spinal curves in the population studied.

5.3 The relationship between multifidus and lumbopelvic muscle size

The final objective of this study was to investigate the correlation between the key stabilising muscles of the spine. Our results showed a significant weak and moderate positive correlation between the CSA of the LES at the L_2 vertebral level and the CSA of the multifidus muscle at the L_4 and L_5 vertebral levels. A positive weak correlation between the LES at the L_3 vertebral level and the CSA of the multifidus muscle at the L_5 vertebral level was also found. These positive correlations are likely to be due to the synergistic muscle action of these muscles, with both muscles involved in extending the lumbar spine. While the multifidus is primarily a spinal stabilising muscle denoted by its morphology (Bogduk et al., 1992) and the LES is primarily a lumbar extensor given its greater moment arm and longer muscle fibres (Aspden, 1992), both muscle groups have a role in extending the spine and controling the lumbar lordosis. This is represented in the correlation of their muscle CSA.

Further, weak positive correlations were found between the CSA of the LES muscle at the L_2 and L_3 vertebral levels, the multifidus muscle at the L_4 vertebral level and the CSA of the Gmax muscle. The proximal attachment of the Gmax muscle has approximately 10% of its fibres attaching to the erector spinae aponeurosis and thoracolumbar fascia and extends up to the L_3 vertebra. This attachment allows the Gmax muscles to exert a small lumbar extension force on the lumbar spine and act in synergy with the LES and multifidus muscles (Barker et al., 2014). While the Gmax muscle acts primarily to extend the hip, its synergistic relationship with the lumbar extensor muscles may help to explain the correlations observed. The Gmax and lumbar extensor muscles are involved in common lower limb strengthening exercises (e.g., back squat, trap bar deadlift and Romanian deadlift) performed by AFL athletes. This training is likely to see simultaneous increases in the strength of the Gmax and lumbar extensor muscles, and commensurate increases in muscle size. Recently a study demonstrated that resistance training resulted in an increase in pelvic anterior tilt during a squat exercise, and increased the functional CSA of the multifidus in participants with low back pain (Welch et al., 2015). With squatting movements aimed at increasing the strength of the Gmax muscle in athletes it is likely that these exercises would have a training effect on the LES and multifidus muscle groups as well, possibly contributing to the correlation seen.

Moderate and weak positive correlations were found between players LES muscles at L_3, L_4 vertebral levels and IO thickness respectively. The thickness of the IO muscle was also weakly correlated with the CSA of the multifidus muscle at the L_4 vertebral level and trended towards significance for the multifidus at the L_5 vertebral level. This correlation may reflect the antagonistic muscle action of the anterior pelvic rotators (multifidus and LES muscles) and the posterior rotation action of the IO muscle. These muscles in combination with others have been described to act like a corset around the lumbar spine to increase the lumbar spines capacity to tolerate compression load (Claus et al., 2009). The ability of these muscles to work together to stabilise the lumbopelvic region may contribute to the relationship in muscle CSAs seen in the current investigation.

The moderate positive correlation between the PM and Gmax muscles may reflect the antagonistic relationship between the hip flexor and hip extensor muscle group. It is beyond the scope of this study to identify the cause of this relationship; however, the close relationship may be of interest for further research.

5.4 Clinical Implications

Identifying weak muscle groups based on postural differences is a common physiotherapy practice. The lack of correlation between the stabilising muscles of the spine and the sagittal curves of the spine in the current investigation may indicate that this practice may not be as accurate as first thought. The common beliefs that lordotic postures are due to larger and stronger ES and multifidus muscle groups and that flat spinal postures are related to weak/small gluteal muscle groups were not supported by this study. Observation of spinal posture in clinical assessments may not be an accurate way of identifying muscle deficiencies or imbalances in AFL athletes. Directly measuring the CSA of spinal muscles using ultrasound imaging or MRI is a more accurate way to identify deficits for rehabilitation purposes.

In utilising both supine MRI and standing X-ray measurements of the spine, a strong correlation between the sagittal Cobb angles of the lumbar lordosis using the two different imaging modalities was found. In the supine position adopted for the MRI images, it could be assumed that the muscles supporting the lumbar curvature of the spine would be relaxed and that the lordosis would be reduced when compared with the standing X-ray. However, this was not the case and the results of the current investigation support the theory that the passive structures of the spine may influence the curvature of the spine more than the supporting muscles. This finding may also help to streamline future research, as MRIs conducted in supine lying, which are commonly performed in clinical practice, were adequate for measurement of the lumbar lordosis.

5.5 Limitations

There are some limitations to the results of this study. Firstly, the results are limited to one AFL team measured at one time point. This limits the generalisability of the results which may be different for teams with different training programs or for different sports. This exploratory study, being a cross-sectional observational study, can show the direction of the relationship between variables but cannot explain the causation of these relationships.

6. Conclusion

The results of this observational exploratory study indicated that there were not any significant correlations between the size of the sagittal curves of the spine and the size of key stabilizing muscles of the lumbopelvic region in elite AFL players. The reasons why a smaller CSA of the multifidus is a lower limb injury risk factor may be complex and multifactorial. The explanation is not as simple as the influence of the muscles on the sagittal curvatures of the spine. However, significant correlations between the LES, lumbar multifidus and Gmax muscles of the pelvis were observed. These findings may provide further insight into the relationship between multifidus muscle size and lower limb injury. Further research investigating the relationship between these muscle groups and injury incidence may help to bridge the gap of why a small multifidus muscle CSA is an injury risk factor in AFL athletes.

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Supplementary Material

Table 4: Muscle size comparison between sides

		Mean	SD	P - Value
L4 Multifidus CSA (cm2)	**Left**	10.14	1.43	0.21
	Right	9.79	1.26	
L5 Multifidus CSA (cm2)	**Left**	10.28	1.4	0.19
	Right	9.86	1.64	
Glut Max CSA (cm2)	**Left**	67.05	7.64	0.682
	Right	67.65	6.54	
QL CSA (cm2)	**Left**	9.33	1.68	0.43
	Right	9.05	1.82	
PM CSA (cm2)	**Left**	23.46	3.31	0.59
	Right	23.1	3.06	
IO thickness (cm)	**Left**	1.47	0.73	0.26
	Right	1.54	0.27	
L2 Erector Spinae (cm2)	**Left**	26.37	3.84	0.96
	Right	26.36	3.62	
L3 Erector Spinae (cm2)	**Left**	23.84	3.56	0.85
	Right	23.78	3.68	

Gmax: gluteus maximus; QL quadratus lumborum; IO internal oblique;
CSA cross section area; cm centimetres